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A NEUTRON COUNTER FOR SMALL SAMPLES*

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Abstract

The Inventory Sample Counter Model IV is the most recent neutron coincidence counter specifically designed to measure small samples. We used a combination of measurement experience and Monte Carlo modeling to design a neutron counter that can provide measurement results with an accuracy of 0.5% or better. Some applications incorporate a high-resolution detector into the neutron counter. This allows the simultaneous measurement of the plutonium isotopics using the passive gamma-ray emission and the measurement of the ^{240}Pu effective mass using the passive neutron emission. The two results are then combined to yield the plutonium mass.

1. Introduction

The Inventory Sample Counter (INVS) was developed to assay small plutonium samples by passive neutron coincidence counting. Small samples typically have little induced multiplication. Therefore, the coincidence measurements are less sensitive to (α, n) impurities in the samples. Consequently, the INVS has the capacity to provide measurements with less bias than is sometimes observed in neutron measurements of large samples.

Use of INVS by the International Atomic Energy Agency (IAEA) throughout the world has demonstrated the practicality of the measurement concept and defined criteria that guided the improvement of the measurement concept. The counter has been upgraded three times /1,2,3/; this is the fourth version of the hardware. We have incorporated our experience with the first three versions into the upgrades and have used the Los Alamos transport code MCNP /4/ to guide the design improvements.

2. Design Optimization

MCNP was used to simulate the INVS counter for the design optimization. Characteristics such as ^{3}He detector length, placement, and number; carbon reflectors, cadmium liners, the construction materials, and the overall dimensions were studied with the computer model. The INVS Model IV design

- increased the neutron detection efficiency,
- decreased the response variation with sample position, and
- created a standard hardware module that interfaces easily to a variety of applications, including

  (1) the traditional, portable, stand alone mode,
  (2) permanent installation coupled to a glove box, and
  (3) coupling to a high resolution gamma ray detector for simultaneous isotopic measurement

For simultaneous neutron and gamma ray measurement, we used MCNP to model the effects of a germanium detector inside the sample cavity. We developed specifications for a germanium detector with the minimum effect on the passive neutron measurement. The germanium detector end cap has a reduced diameter (3.8 cm), and is 15 cm long. High-density polyethylene is placed behind the germanium crystal inside the vacuum canister to maintain optimum moderation for neutron detection in the INVS.

3. HARDWARE

Figure 1 shows the INVS Model IV, with the germanium detector inserted in the bottom end cap, ready for simultaneous measurements. The operator is loading a sample into the sample holder. The sample holder is inserted into the INVS Model IV through the top of the counter. Figure 2 is a cross section view of the INVS Model IV without the germanium detector. Table 1 lists technical specifications for the neutron detection hardware.

As seen in Fig. 2, the 18 proportional counters are arranged in 2 rings of 9 detectors each. The inner ring is located at a radius of 7.2 cm centered on the sample. The outer ring is located at a radius of 10.6 cm centered on the sample. Three AMPTEK preamplifiers /2/ are used for the two rings of ^{3}He proportional counters. The proportional counter electronics are adjusted differently from the settings

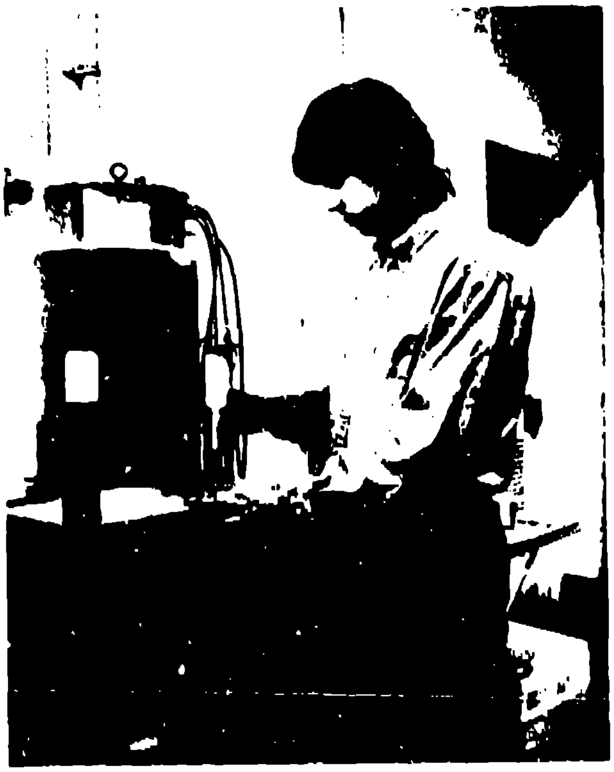

Fig. 1. The combined small sample assay system. The electronics are in the background behind the user. The INVS Model IV is seen above the cryostat for the germanium detector. The user is loading a small sample into the sample holder for a measurement.

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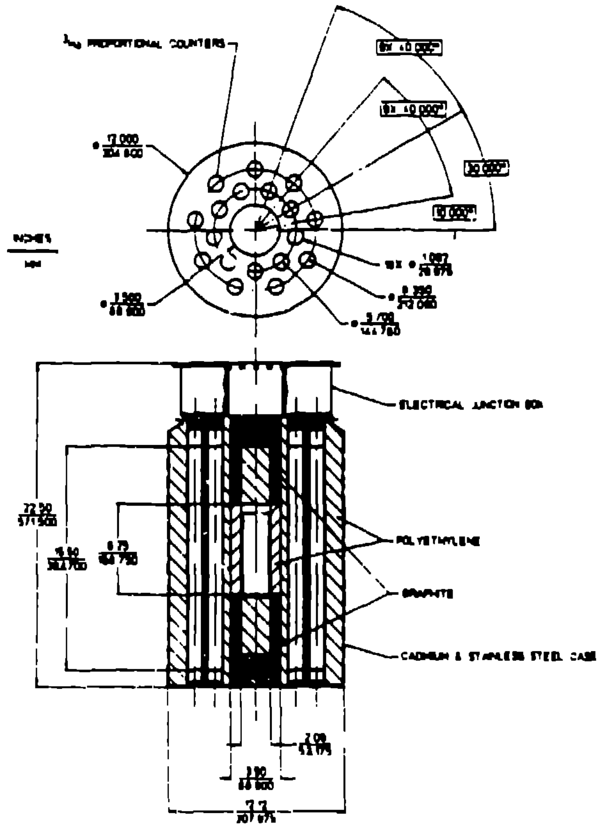

Fig. 2. Cross-section views of the INVS Model IV geometry. Dimensions are given in both inches and millimeters. The bottom end plug without the germanium detector is shown.

Table 1. Technical Specifications for INVS Model IV	
Weight	50 kg
Diameter	30.8 cm
Length	57.2 cm
Number of Detectors	18
Detector Model Number	RS P4 8015 106
Detector Active Length	39 cm
^{3}He Pressure	6 atm
Sample Chamber Diameter	4.9 cm
Sample Chamber Height	15 cm (11 cm with Ge detector in place)
Cadmium Liner	No
Graphite in End Plugs	Yes

Table 2. Recommended Settings	
High Voltage	1780 V
Gate Length	64 µs
Pre Delay	4.5 µs

Table 3. Performance	
Totals Efficiency	43.5%
Die-Away Time	54 µs
Deadtime Coefficients	a = 1.15 µs
(3 Amptek channels)	b = 0.575 µs^2
Axial Flat Region[a]	11 cm (7 cm with Ge detector in place)

[a]Reals response deviation of ± 1% or less.

used for 4-atm ^{3}He proportional counters. We used a threshold adjustment for the AMPTEK preamplifiers that provided a count rate at 1250 V equal to 1% of the count rate at 1780 V. Table 2 lists recommended settings for the high voltage and shift-register coincidence electronics.

The performance characteristics of the INVS Model IV, as measured with small ^{252}Cf sources, are summarized in Table 3.

4. USES OF THE COUNTER

The INVS Model IV measurement head was designed to be readily adaptable to a variety of applications. Four will be discussed.

Measurement of Samples Inside a Glove Box

The INVS counter may be used to measure samples inside a glove box without the requirement of bagging out. A cylindrical sample well extension from the floor of the glove box extends down into the sample cavity. The sample holder and top end plug are within the glove box, the rest of the measurement head is outside of the glove box. The INVS has been used in this way at the automated MOX fuel fabrication facility, PFPF, in Japan. Operators measure small samples of MOX powder and fuel pellets by the INVS without bagging out the samples.

Attainment of High Accuracy and Precision

The new INVS design provides measurement results of high accuracy and precision. The high neutron detection efficiency provides better precision by providing better counting statistics. The minimal effect of changing the sample position within the measurement chamber provides better accuracy by providing a flatter axial response. Two field measurement campaigns have recently evaluated the INVS Model IV performance with well characterized reference materials. Accuracies of 0.5% were achieved at both facilities in reasonable count times. The largest measurement uncertainty in these results came from the counting statistics.

The evaluation in support of the On Site Laboratories used low burnup plutonium samples and counting times of approximately 12 hours /5/. The plutonium masses ranged from 0.5 to 5 g. Statistical filters were used to eliminate coincidence bursts from electrical noise, cosmic ray spallations, and room background. Accuracies of one to two tenths of a percent were documented. Measurements with 2 h count times on the larger masses demonstrated accuracies of 0.5%.

The evaluation at JRC Ispra was part of an IAEA physical inventory verification training exercise /6/. The samples were high burnup plutonium powder, mixed oxide (MOX) pellets, and MOX powders. The sample masses for the plutonium oxide and MOX powders were 8 g. The pellets were smaller, typically 2 to 6 g. Count times varied from 300 to 1200 s. A few samples were counted during the lunch breaks for 3000 to 4000 s. Half percent accuracies were documented for the powder samples. Longer count times and statistical filtering of the data would improve the results. This evaluation also demonstrated the importance of sample positioning for improving measurement accuracy. Differences in geometry between pellets and powder and differences in the containers both impacted the accuracy of the measurement results. The presence of HEU in some of the MOX items caused a measurable bias because of sample multiplication.

Simultaneous Measurement of Isotopics and ^{240}Pu Effective Mass

We combine traditional neutron coincidence measurements with knowledge of the plutonium isotopics to calculate the plutonium mass from the measured neutron count rates. The INVS Model IV can be outfitted with a bottom end plug that allows the insertion of a germanium detector into the sample cavity. A customized germanium detector is used to minimize the effects on the neutron counting. Tin filters were used for the germanium detector because the use of cadmium would impact the neutron detector efficiency. The bottom of the sample holder is raised 4.13 cm when the germanium detector is in position. This configuration allows simultaneous measurement of the passive gamma-ray signal and the passive neutron signal. The sample plutonium mass can be determined from this measurement configuration alone.

We are presently evaluating the performance of the combined INVS and isotopics system at Los Alamos. The addition of the germanium counter does not have a significant effect on the accuracy of the INVS neutron measurements. The neutron detection efficiency is decreased 0.2% by the germanium detector. Table IV lists preliminary results for measurements on six samples.

Table IV. Isotopics Measurement Results

Sample ID	fraction ^{240}Pu effective		Count time
	known	measured	
PIDIE 1	0.0605	0.0608 ± 0.0018	3000 s
PIDIE 2	0.1462	0.1470 ± 0.0012	3000 s
PIDIE 5	0.2273	0.2249 ± 0.0028	3000 s
PIDIE 7	0.3690	0.3490 ± 0.0073	2000 s
GIEL 84	0.1501	0.1475 ± 0.0010	1000 s
GIEL 61	0.3598	0.3405 ± 0.0037	1000 s

Count times of 1000 to 3000 s allow us to measure the fraction of ^{240}Pu effective with an uncertainty of 1 to 3%. We expect that larger samples will be measured with an uncertainty of approximately 0.5% in an hour.

Estimation of the (α, n) Rate

Sample multiplication is generally negligible for small samples of plutonium. Consequently the multiplication correction is not generally used for INVS data reduction. The INVS Model IV can be used to measure the ^{240}Pu effective mass and the (α, n) neutron rate for these non multiplying samples. This measured alpha value can then be used for the bulk items that are represented by the small sample in the INVS counter. The bulk items could be measured using existing equipment and the known alpha analysis method /7/.

The neutron coincidence count rate determines the ^{240}Pu effective mass. For nonmultiplying samples, the coincidence count rate can be combined with the total neutron count rate to provide an estimate of α, the ratio of the (α, n) and spontaneous fission rates. Since changes in the neutron energy affect the neutron detection efficiency, the INVS Model IV can read the ^{3}He detector rings separately. The ratio of the inner to outer total neutron count rates can be used to provide an efficiency correction for the (α, n) neutrons that generally differ in energy from the fission neutrons. This method of estimating α requires an accurate totals measurement, which implies an accurate value for the background rate. This method is being evaluated at Los Alamos with impure samples of PuO_2.

SUMMARY

The measurement goal of high accuracy has been achieved. Two different field evaluations have demonstrated half-percent or better results for the neutron coincidence counting of small samples. Both on-site laboratory use and inspectors with portable equipment can take advantage of this improvement in the technique. The addition of the isotopics capability will make the INVS less portable, but for some applications the high-resolution gamma-ray spectrometry hardware is available at the inspection site. The ability to count the gamma-ray and neutron signals simultaneously is attractive to inspectors.

The glove-box installation of the INVS is being used frequently. It has the advantage of reducing the sample handling by personnel and reducing the waste generated by the bag out procedure. The increased interest in minimizing mixed waste should help direct more attention to the INVS Model IV as a potential measurement technique.

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